BNL Strategic Plan for High Energy Physics

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Abstract: The strategic plan for High Energy Physics at Brookhaven National Laboratory seeks to align itself with the strategic goals of the U.S. Department of Energy[1] and to maximize the scientific contributions of the Laboratory to the advance of particle physics. We also assume, following policy guidance from DOE, that some aspects of the field of Astrophysics/Cosmology will become part of the HEP program in DOE. To accomplish these guiding principles, we seek to identify strategic research directions that allow BNL to offer unique scientific and technical expertise, together with existing and newly constructed accelerator facilities at BNL, to pursue innovative and productive paths for advancing these scientific fields. We capture our plan in abbreviated form in a simple matrix that is explained, project-by-project, in the sections below. In the matrix, the *data taking periods* are shown vs. time without their relevant construction periods. The data taking periods, of course, are when these experiments begin contributing to the advance of particle physics and cosmology. For this reason, an important future facility, the International Linear Collider is not shown in the matrix. We also note the impact of theory and Accelerator R&D activities in the text.

Time Interval	FY05-06	FY07-08	FY09-10	FY11-12	FY13-14	FY15-16
Physics Beyond the Standard Model	D0	ATLAS D0 E949	ATLAS D0 μ(g-2)	ATLAS KOPIO MECO	ATLAS KOPIO MECO	ATLAS KOPIO MECO
Neutrino Physics	MINOS	MINOS	MINOS		VLBNO Exp.	VLBNO Exp.
Astrophysics				LSST	LSST	LSST
Theory	Analytic & Lattice	Analytic & Lattice	Analytic & Lattice	Analytic & Lattice	Analytic & Lattice	Analytic & Lattice

Executive Summary of the Plan

The strategic plan for High Energy Physics at BNL continues the historical mission of the U.S. Department of Energy (DOE) National Laboratories as sites for accelerator based user facilities for experimental programs that are not practical for construction and operation in university venues. These large national facilities are intended for use by qualified researchers from all interested universities plus other research institutions in the U.S. and abroad to advance the field of particle physics. In pursuing this plan, we assume that the national program will be guided by a principle of maximizing important particle physics advances relative to invested resources and that the current tight funding circumstances will not soon improve. Because the AGS-based portions of this plan require the investment of significant new resources by the DOE and the National Science Foundation (NSF), as well as by collaborating institutions abroad, we are constrained to assume that resources will be allocated nationally on a model of maximizing science value. This principle has been proclaimed by administration policy makers. The policy also applies to the LHC ATLAS research program, managed for U.S. researchers by BNL as the U.S. Host Laboratory, and to the Astrophysics/Cosmology elements of the program. Important policy priorities for future U.S. HEP programs have been provided by the U.S. Government[2], and by the DOE's High Energy Physics Advisory Panel[3]. BNL's plan aligns well with this guidance.

[1] "Facilities for the Future of Science", http://www.science.doe.gov/Sub/Facilities_for_future/facilities_future.htm
[2] "Physics of the Universe", OSTP, February 2004, http://www.ostp.gov/html/physicsoftheuniverse2.pdf
[3] "Quantum Universe", HEPAP Quantum Universe Committee, http://interactions.org/quantumuniverse

We also note the particular value and applicability to our plan of the installed accelerator capability at BNL, especially the Alternating Gradient Synchrotron (AGS) and its injector machines, an accelerator complex that is currently operating as the injector system for the Relativistic Heavy Ion Collider (RHIC) and its nuclear physics research program at BNL. The flexibility and rather low duty-cycle use of the AGS injector complex for the RHIC needs provides a very economical basis for also employing the AGS as the centerpiece machine for the contemplated HEP program proposed in this strategic plan. In January 2004, a special review panel of the DOE examined the feasibility and impact on the RHIC program of using the AGS complex for other scientific missions in a parasitic mode and concluded that there were no significant negative impacts on RHIC. In fact, the panel concluded that more intensive use of the AGS would, in fact, improve its operational reliability, hence providing a net positive benefit to the RHIC program. This is a key result for the practicality of our HEP plan.

Next, we point out that two key elements of this plan, the ATLAS Research Program and the RSVP experiments KOPIO and MECO, have already been approved by DOE and NSF and funding has been planned and provided for carrying out these important particle physics activities. Funding has also been provided by DOE for the QCD-On-a-Chip (QCDOC) supercomputer at BNL that will provide powerful supercomputing capability for the national Lattice Gauge Physics theory community. This machine will be combined with an identical QCDOC operated by the Riken BNL Research Center at BNL to provide the U.S. with a particularly strong capability (20 Tflops peak) dedicated to advancing the growing and important field of lattice gauge physics.

Two more of our proposed projects, the Very Long Baseline Neutrino Oscillations (VLBNO) Experiment and the Large Synoptic Survey Telescope (LSST) were listed in a key U.S. Government policy document[2] with an indication that these new experiments are high in priority for the future national program in particle physics and cosmology. We are hopeful that these two projects will move ahead in the next few years to the status of approved and funded construction projects.

In terms of near-term and ongoing research programs, we note the involvement of BNL physicists in the D0 and MINOS Experiments at Fermilab and observe that these will make contributions to the national program over the next few years. BNL has contributed to the design and construction of both experiments and continues to participate in their research programs.

Finally, we note that there are two near-term proposed experiments that have achieved the highest "Must Do" ranking from the BNL HENP Program Advisory Committee[4]. One of these, E949, actually completed one DOE supported data run in 2002 and demonstrated that the experiment worked as proposed before being shut down by DOE for budgetary reasons. The other, an improved version of the precision Muon (g-2) measurement, proposes the continuation of the very successful earlier version of the experiment at the AGS with important improvements. We are hopeful that the evolution of the national program will be such as to allow a reevaluation of priorities for the best science and that such an outcome will allow these two very important and low-cost experiments to go forward in the next few years.

BNL supports ongoing theoretical physics plus advanced accelerator and superconducting magnet R&D programs that are related to the advance of the particle physics agenda. These programs are commented on in the main text. To put the new BNL initiatives in a realistic operational time context, we also include an R&D/Construction matrix as a separate section of the text below.

[4] BNL HENP Program Advisory Committee Recommendations, http://www.bnl.gov/henp

Contributions of the Strategic Plan Experiments to the Advance of Physics

Each of the physics projects in the abstract matrix is briefly discussed in the paragraphs below, noting both their contributions to world physics and their approval or operational status in the national forum. The experiments are discussed in rough time order of data taking, starting with experiments that are currently actively taking data or that could be re-activated in a short-term time frame. The construction/preparation periods are of significantly varying duration among the new or future projects and these periods do not contribute directly to the advance of the relevant science areas. Therefore, we take the *availability of new scientific results from the experiments* as the appropriate measure of their scientific impact. In the last section of this plan, we address the construction activities in a second matrix to provide a more complete picture of Laboratory activity.

D0 Experiment[5]: This experiment has been active for over twenty years at the Fermilab Tevatron and is now primarily focused on searches for the postulated Higgs particle(s) and for experimental evidence for the existence of Super Symmetry (SUSY). The physics reach of D0 is strongly limited relative to physics that can be achieved when the LHC experiments come on-line, but the LHC will not commence experimental operations until about 2007 and this opens a window of opportunity for D0. BNL hadron collider program physicists expect to continue to run on D0 until the ATLAS program begins and will then turn their attention fully to ATLAS (see below). Many of the techniques and analysis skills used on D0 will be transferable to the ATLAS analysis environment.

MINOS[6]: This experiment will explore specific aspects of neutrino oscillations starting with the commencement of data taking in 2005. MINOS expects to decrease the experimental error in the measurement of the $\sin^2(2\theta_{23})$ and Δm^2_{32} parameters that characterize the disappearance of muon neutrinos as they fly away from their production point. BNL physicists joined the MINOS Experiment in 1999 a few years after its approval in 1996. The BNL collaborators have contributed to the construction of the experiment and will participate in the data taking and analysis phases scheduled to begin in 2005.

E949[7]: This experiment seeks to expand the discovery of the very rare decay process $K^+ \rightarrow \pi^+ \nu \bar{\nu}$, first detected in AGS Experiment E787, to a 20% measurement of the decay rate by operating the improved E949 version of this experiment for a significantly longer beam exposure. This experiment is one of two very important rare kaon decay channels that provide direct measurements of the CP-violation parameters, ρ and η, in the Standard Model (SM) of particle physics. The second channel is the decay rate of the neutral kaon, $K^0 \rightarrow \pi^0 \nu \bar{\nu}$, that will be measured in the upcoming KOPIO experiment discussed below. These two very rare kaon decay rates are the s-quark equivalents to CP-violation measurements in the b-quark system, currently in process in the BaBar experiment at SLAC and the Belle experiment at KEK in Japan. Both kaon and B-meson systems assume the same values of ρ and η in the SM; any discrepancy between the s-quark and b-quark CP-violation parameters between systems necessarily indicates physics beyond the SM. E949 is ready to run again whenever AGS operations funding can be provided. The experiment has no significant new capital funding needs or significant competition for proton beam use from other AGS experiments in the FY05-07 time frame.

Muon (g-2) Experiment[8]: The physics outcome of the Muon (g-2) Experiment at AGS that ran

[5] D0 Experiment website, http://www-d0.fnal.gov/
[6] MINOS Experiment website, http://www.phy.bnl.gov/edg/edg.html , click on MINOS.
[7] E949 Experiment website, http://www.phy.bnl.gov/e949 .
[8] Muon (g-2) Experiment website, http://www.g-2.bnl.gov/index.shtml .

from 1998-2003 at BNL, with all experimental data now analyzed and published, is that there is a 2.7σ discrepancy between the present experimental measurements and the theoretical predictions of the Standard Model (SM) of particle physics. The best theory predictions currently derive from data taken by two different e^+e^- collider experiments and these are considered the most reliable predictions by theory experts in the field. Alternate theoretical SM predictions derived from τ-lepton decays exhibit a smaller discrepancy with the μ(g-2) measurements but these theory predictions are not considered reliable at the present time by the same experts. If the present theory/experiment discrepancy is sustained with decreased statistical and systematic uncertainties, especially on the experimental side with an improved μ (g-2) experiment and improved statistics, it will herald the first clear evidence of physics beyond the SM. The search for deviations from the SM has been pursued avidly by the world particle physics community for decades, so far without clear evidence of any reproducible discrepancy. This strong physics motivation stimulated the existing μ(g-2) group to submit a new proposal to BNL in 2004 that proposes small but important upgrades to the experiment that, along with two more years of data taking, could reduce the experimental error by a factor of 2.5. This result, along with anticipated improvements in reduction of the theoretical error, could change the current discrepancy from 2.7σ to 5σ. Even if the improved μ(g-2) result emerged *after* the first measurements at the LHC, it would still have great value in helping to unravel the underlying structure of new physics, especially if the LHC discovers Super Symmetry (SUSY). In this case, the μ(g-2) measurement could determine the size of the SUSY parameter tan(β). These considerations led the BNL HENP Program Advisory Committee to award the continuation of μ(g-2), a unanimous rating of "Must Do", the first time this highest rating was unanimously awarded by the PAC. If approved and funded by DOE, the experiment will require capital improvements on the scale of several millions of dollars and two years of data taking. It could run as early as the FY07-09 time frame, well ahead of completion of the KOPIO and MECO experiment construction projects at AGS.

ATLAS Experiment[9]: The ATLAS Experiment at the CERN Large Hadron Collider (LHC) will be the most important particle physics experimental venue, worldwide, for the coming decade and will take first priority in the BNL particle physics experimental program. The LHC scientific program is almost certain to reveal the existence of the long sought Higgs particle(s) believed to underlie the nature of mass. ATLAS may also (possibly) see the first explicit production of super-symmetric (SUSY) particles, the postulated super-partners of the existing fermions and bosons that form the basis of the Standard Model (SM) of particle physics. The U.S. is deeply involved and committed to the success of the LHC program and has provided approximately 20% of the capital costs for each of the two major LHC particle physics detectors, ATLAS and CMS. A comparable fraction of the particle physicists participating in each of these giant experiments are U.S. based. U.S. participation in the ATLAS Experiment's Construction Project and Physics Research Program has been managed by BNL as the Host Laboratory for US ATLAS. BNL also manages U.S. participation in the R&D program for future ATLAS detector upgrades. BNL has started a Physics Analysis Center for ATLAS that will facilitate U.S. physics collaborators to participate fully in the ATLAS research enterprise from their home institutions.

RSVP - KOPIO & MECO Experiments[10]: Two new Rare Symmetry Violating Processes (RSVP) experiments at the AGS, KOPIO and MECO, have been accepted for construction by the National Science foundation (NSF) and were recently funded by Congress as a new NSF Major Research Equipment & Facilities Construction (MREFC) project under the RSVP project heading. Both of

[9] ATLAS website, http://www.usatlas.bnl.gov/ and http://atlas.web.cern.ch/Atlas/Welcome.html
[10] RSVP websites:, http://www.bnl.gov/rsvp/ ; http://www.phy.bnl.gov/edg/edg.html ; http://meco.ps.uci.edu/

these experiments probe physics beyond the Standard Model (SM) in ways that bring important and unique new knowledge to particle physics. The KOPIO Experiment seeks to measure the rate for the very rare neutral kaon decay, $K^0 \rightarrow \pi^0 \nu \bar{\nu}$, a process that provides a direct and theoretically unambiguous measurement of the η parameter in the SM prediction for CP-violation in the s-quark sector. Combined with a determination of the equivalent charged kaon decay process, $K^+ \rightarrow \pi^+ \nu \bar{\nu}$, a process that we anticipate will be measured in AGS Experiment E949, a complete characterization of CP-violation in the s-quark sector can be obtained in the context of the SM. What is important here is that these measurements in the kaon sector are an independent measurement of the SM parameters, ρ and η, now being pursued in B-meson processes in the BaBar (SLAC) and Belle (KEK) experiments in the U.S. and Japan. If *different* numerical values of these parameters are seen in the s-quark and b-quark systems, this will constitute clear evidence of physics beyond the SM. The MECO Experiment seeks to observe the SM-forbidden, lepton-violating decay process, $\mu^- \rightarrow e^-$ directly from atomic orbit, allowing energy and momentum to be transferred to the nucleus, thereby conserving energy and momentum while also violating one of the important fundamental symmetries of the SM. Such a lepton-number violation is allowed in most theories of physics beyond the SM, so the observation of this decay is unequivocal evidence for non-SM physics. The reach of MECO in mass scale (hundreds of TeV) far exceeds any contemplated future collider facility at any currently conceivable energy. The RSVP experiments have both been favorably noted in the recent "Quantum Universe" report from the High Energy Physics Advisory Panel[2] and are strongly supported by the NSF.

<u>LSST[11]:</u> Numerous decadal surveys and governmental policy documents, including two by or for the DOE[2,3], have recommended the construction of the Large Synoptic Survey Telescope (LSST) to survey the entire visible sky every few days. A single set of LSST observations will support a wide range of scientific programs. Of particular interest to BNL is a new investigation into the nature of Dark Energy. This program places the most stringent requirements on telescope performance:

- Excellent image quality – FWHM <0.7 arcsec in two of five filter bands, control of point spread function shape, and deep summed images
- Many short exposures (10-15 sec) to control systematics and to obtain a sufficient depth in the summed images (29th AB per square arcsec, in 5 filter bands)
- Photometric redshifts to better than 2% absolute photometric precision
- The tracking of image quality and rapid response to changing observing conditions requires simultaneous data reduction, with latency not longer than a few minutes

Other science enabled by the same data set includes a Solar System map including moving objects, Optical Transients, with real time alerts, and Galactic Structure. The baseline design calls for telescope with a field of view of 10 square degrees, an 8.4-m primary mirror and a 3-gigapixel camera with a scale of 0.2 arcsec per pixel. The DOE institutions propose to take responsibility for the design and construction of the camera. Under this plan BNL would have primary responsibility for the 3-gigapixel focal plane array of silicon detectors – the heart of the camera. BNL and other DOE institutions have been working on the camera design for more than a year on internal funds. LSST is presently requesting R&D funding from DOE and NSF starting in FY 2005. Construction could start in FY 2008 and first light on the telescope could be achieved in FY 2012.

<u>VLBNO Experiment[12]:</u> The Very Long Baseline Neutrino Oscillations Experiment (VLBNO) is a bold new particle physics initiative to precisely measure *the complete set of neutrino oscillation parameters* in a single experiment. The BNL method includes determination of the CP-violation

[11] LSST website, http://www.lsst.org/
[12] Very Long Baseline Neutrino Oscillations Experiment website, http://www.bnl.gov/henp

parameter δ in an unambiguous way, a result still thought by some to require a suite of several distinct and separate experiments. Neutrinos, long considered to be massless particles, have now been shown to have small but finite masses and, as a result, to experience lepton flavor oscillations among their mass eigenstates as they fly through space. The reason that this recent development is so important to particle physics (and for cosmology) is that the finite masses and oscillation properties of neutrinos will open new pathways for investigating cosmological as well as particle physics questions of profound and fundamental importance. Perhaps, the most important of these is the possibility that CP-violation in the lepton sector is large and may drive the asymmetry of matter over anti-matter in the universe, an outcome that has only recently been discussed by theorists. Intimately connected to the VLBNO Experiment is the availability of a "Super Neutrino Beam" that would deliver an intense flux of accelerator-produced neutrinos to a very large (Megaton-class) experimental detector located deep underground at a distance of about 2000 km from the neutrino source. An excellent candidate experimental site for this purpose would be the "Deep Underground Science and Engineering Laboratory" (DUSEL), recently announced by the National Science Foundation[13], assuming that one of the Rocky Mountain west sites is chosen for DUSEL. The detector needs of the VLBNO Experiment are also fully compatible with other important parts of the anticipated DUSEL scientific program, such as a next-generation nucleon decay search and a neutrino observatory for astrophysical neutrino sources[14]. The time frame for the VLBNO is farther out than many of our initiatives but is likely to become a leading U.S. experiment in the future HEP program and will require planning and R&D involvement that is already initiated. The recently completed APS Neutrino Physics Study awards this physics high priority[15].

Theoretical Physics[16]: The High Energy Theory Group at BNL is one of the strongest in the country and focuses on the connections between theory and experiment, especially experiments of particular interest to the BNL experimental HEP community. The theory group plays a clear and strong leadership role in pointing the BNL HEP community towards important and productive new physics directions. Members of the group are active in developing the physics cases for future neutrino experiments and will play important roles in studying LHC physics and in interactions with the future ATLAS analysis center at BNL. In addition to a strong focus on analytical methods and phenomenology, the group actively contributes to lattice gauge calculations in both HEP and NP areas of interest. Maintaining the strength and effectiveness of the theory group, and its focus on the most important areas of particle physics for the continued advance of the overall BNL HEP program, will continue to be a primary goal of BNL. On the lattice gauge side, the QCDOC supercomputers now being installed at BNL will support the lattice gauge calculations with state of the art supercomputer resources.

Advanced Accelerator R&D[17]: The program of advanced accelerator R&D at BNL is currently focused on two areas of activity: 1) experiments in the Accelerator Test Facility (ATF), a national user facility that utilizes a 70 MeV electron linac and high power CO_2 laser to interact electron and photon beams in a series of investigations of new concepts in accelerator physics; 2) studies of the technical feasibility and cost of novel schemes to store muon beams as the source of kinematically well-defined neutrino beams or as the means of creating a muon-muon beam collider. The ATF has been a unique resource for the accelerator science community since 1992 and produces research papers on important accelerator topics every year. The Advanced Accelerator Group in the Physics

[13] DUSEL website, http://www.nsf.gov/pubs/2004/nsf04595/nsf04595.htm
[14] UNO website, http://ale.physics.sunysb.edu/uno/about.shtml
[15] APS Neutrino Study website, http://www.interactions.org/cms/?pid=1009695
[16] BNL HEP Theory website, http://quark.phy.bnl.gov/
[17] BNL Advanced Accelerator R&D website, http://www.cap.bnl.gov/mumu/

Department focuses on schemes to accelerate and store muons (muon storage rings) to create sources of neutrinos, or (a much larger challenge) accelerate muons to energies where the muon beams could function as a muon-muon collider, providing a new tool for the investigation of particle physics research topics. Both of these accelerator R&D programs have gone forward for many years and should be regarded as ongoing activities rather than as specific targeted physics initiatives.

Superconducting Magnet R&D[18]: The Superconducting Magnet Division (SMD) at BNL pursues the dual mission of developing novel and useful new superconducting (SC) magnet designs and materials as well as building small numbers of superconducting magnets that are not cost-effective for industry to produce or for other laboratories around the world to design and build themselves. Currently important for the U.S. accelerator and associated magnet R&D communities, is the participation of SMD in the DOE's LHC Accelerator Research Program (LARP), a new program that involves three DOE Laboratories in the planned commissioning, operations and Upgrade Program for the LHC Collider facility. Beyond LARP, as HEP moves into an era where linear accelerators are moving into a spot of prime interest (the ILC, primarily), a need remains for state-of-the-art SC focusing magnets at the interaction regions. Although this may sound like a specialized area of expertise, it is of vital importance to the development of new accelerators around the world. BNL has led the field with key innovations in this area for many years and expects to continue this R&D mission along with the design and fabrication of small numbers of specialized SC magnets.

[18] BNL Superconducting Magnet R&D website, http://www.bnl.gov/magnets

R&D and Construction Projects Matrix

To indicate a time context for carrying out the construction phase of projects shown in the physics impact matrix of the Abstract for this plan, we show a second matrix here that provides BNL projected R&D and Construction Project (C) time frames that lead to the Operations (Ops) periods shown in the physics impact matrix. The periods shown as operations include commissioning time in cases where this is needed. Experiments with no construction required are not shown here.

Project	FY05	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14	FY15	FY16
μ(g-2)	R&D	C	C	Ops	Ops							
MINOS	C	Ops	Ops	Ops	Ops	Ops	Ops					
ATLAS	C	C	C	Ops	Ops	Ops	Ops	Ops	Ops	Ops	Ops	Ops
KOPIO	R&D	C	C	C	C	C	Ops	Ops	Ops	Ops	Ops	
MECO	R&D	C	C	C	C	C	Ops	Ops	Ops	Ops	Ops	
LSST	R&D	R&D	R&D	C	C	C	C	Ops	Ops	Ops	Ops	Ops
VLBNO	R&D	R&D	R&D	C	C	C	C	C	Ops	Ops	Ops	Ops
ILC	R&D	R&D	R&D	R&D	R&D	C	C	C	C	C	C	C